BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

IMAGES ARE BEST AVAILABLE COPY.

As rescanning documents *will not* correct images, please do not report the images to the Image Problem Mailbox.

Patent Office
Canberra

I, JULIE BILLINGSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2003904183 for a patent by WOODSIDE ENERGY LIMITED as filed on 08 August 2003.

WITNESS my hand this
Twenty-eighth day of January 2004

J. Billingsley

JULIE BILLINGSLEY
TEAM LEADER EXAMINATION
SUPPORT AND SALES

APPLICANT: WOODSIDE ENERGY LIMITED

AUSTRALIA

PATENTS ACT 1990

PROVISIONAL SPECIFICATION

FOR THE INVENTION ENTITLED:

"METHOD FOR COMPLETION OR WORK-OVER OF A SUB-SEA WELL USING A HORIZONTAL CHRISTMAS TREE"

The invention is described in the following statement:-

Field of the Invention

The present invention relates to a method of completing a sub-sea well using a horizontal christmas tree.

The present invention further relates to a method of performing a work-over operation on a sub-sea well using a horizontal christmas tree.

The present invention further relates to a sub-sea well and particularly, though not exclusively to sub-sea wells used for oil and/or gas production, as well as sub-sea wells relying on gas and/or water injection.

Background to the Invention

Typically, a sequence of particular steps is used to prepare a sub-sea well for production after drilling is completed. This sequence of steps is referred to as "well completion". The point at which the completion process begins depends on the type and design of the well. Well completion may thus refer to a simple operation of placing a packer or tubing and/or other downhole completion assemblies in an open-hole completion to a more complex processes of installing a series of tubing strings hung from a tubing hanger in combination with a christmas tree.

From time to time during the life of a producing well, remedial action or repairs or maintenance are required. Such operations are referred to as work-over operations. When it is required to perform a work-over operation, a similar series of actions to those followed during well completion are conducted in a different sequence.

It is a statutory requirement in many jurisdictions to ensure that a sub-sea well is provided with two independently verified barriers at all times during the well completion and/or suspension stages as well as during

work-over operations. It is to be understood that the term "barrier" as used throughout this specification includes a physical barrier such as a plug, a test or production packer, a valve, or a shear disc provided that it is possible to independently test the ability of the barrier to hold formation pressure. It is to be understood that the term "barrier" also includes an unperforated liner and/or the head of a column of fluid within a pipe. Moreover, the barrier(s) need not be retrievable.

In typical prior art completions for sub-sea operations, a sub-sea blowout preventer (BOP) stack is run to a well-head to provide supplementary well control during both the drilling and the completion phases until such time that the required barriers have been established elsewhere.

It is standard practice for the various pieces of piping and equipment to be installed during completion to be run through a bore of the sub-sea BOP stack and its associated marine riser that connects the sub-sea BOP stack to a surface rig. To accommodate the running and installation of the equipment during completion, BOP stacks typically have a nominal bore of 18¾ inches. The time taken to run and/or retrieve a BOP stack will depend upon water depth and may take several days. Once the sub-surface BOP is installed, further casing strings are installed in the well, followed by a liner that extends below the lowest casing string typically extending through an oil/gas formation. The liner is typically hung from a liner hanger used to attach or hang the liner from an internal wall of the lowermost casing string.

It is a common practice to install one of the two required barriers at the top of the liner with the second barrier being routinely installed higher in the well, typically in

the casing string adjacent to the well head. After installation, each of these barriers is independently pressure tested to ensure their integrity. At this point the well is referred to as being "suspended".

Having drilled and suspended the well, the sub-surface BOP and its associated marine riser are removed from the wellhead and/or returned to the rig to allow for completion of the well. For many years, the standard industry practice was to install a tubing hanger from which a tubing string is hung in the well head with a conventional (vertical) christmas tree installed above the well head.

In more recent times, horizontal christmas trees have been preferred to conventional (vertical) trees due in part to the ability to provide a greater number of penetrations through a tubing hanger installed in the body of a horizontal christmas tree compared with a tubing hanger installed in the well head. Moreover, when remedial action is required to be performed on a tubing hanger, it has been necessary in the past to remove the conventional christmas tree to retrieve the tubing hanger and pull the tubing string from the well.

As horizontal christmas trees have no valves in their vertical bore, it is standard practice to re-run the BOP stack to the horizontal christmas tree at the top of the well to supplement well control during the remainder of the completion phase to satisfy the statutory requirement for two independent barriers.

Once the BOP stack has been reinstalled on top of the horizontal christmas tree, it is standard practice to remove the uppermost barrier, i.e. the one located in the casing string, to facilitate installation of a tubing string suspended from a tubing hanger. A tubing hanger

running tool is used to run the tubing string and tubing hanger down the bore of the marine riser and through the internal bore of the sub-sea BOP stack.

The tubing hanger is oriented, landed and locked inside the body of the horizontal christmas tree sub-sea. The tubing string may be provided with a downhole safety valve which may serve as one of the two required independent barriers.

During the well completion phase, a sub-sea test tree is typically utilised within a landing string extending from the tubing hanger running tool to the rig and is installed above the tubing hanger running tool. The sub-sea test tree is an expensive piece of equipment that is routinely hired. Moreover, a well operator must incur the additional expense of manufacturing suitable interfaces between the tubing hanger running tool and the landing string as well as between the BOP stack and the sub-sea test tree to suit the particular model of sub-sea test tree being hired.

After the integrity of the downhole safety valve has been confirmed using in-flow testing, a second barrier, typically a wireline plug, is installed in the tubing hanger. When the integrity of each of these barriers has been established, the tubing hanger running tool and sub-sea test tree can be recovered to the drilling rig. It is common practice to use the tubing hanger running tool and sub-sea test tree to install an internal tree cap having a further barrier within the internal tree cap. Alternatively, the tubing hanger and internal tree cap may be run in a single assembly.

The sub-sea BOP stack may be retrieved once the two independent barriers have been verified and the well is ready for production. The final step in a typical prior art well completion sequence is to install a debris cap on

top of the horizontal christmas tree, usually by using a remote operated vehicle (ROV).

The well completion sequences of the prior art involve several problems. Firstly, any operations that must be performed at the well head are limited to tooling which can pass through the internal diameter of the bore of the BOP stack. Secondly, the bore of the BOP stack and/or the marine riser may contain debris such as swarf, cement and/or cuttings in the rams or annular cavities of the BOP stack, debris in the drill and/or choke lines and/or corrosion product in the marine riser. Consequently, one of the major problems with current well completion practice is the level of debris that accumulates in the horizontal christmas tree as a direct result of the need to run the tubing hanger and/or the tree cap through the bore of the BOP stack and the marine riser for sub-sea installation of the tubing hanger. Thirdly, the setting and/or retrieving of a plug in the internal tree cap requires a separate trip of the tubing hanger running tool and sub-sea test tree.

Typically, well completion and work-over operations are very expensive and directly proportional to amount of rig time that must be allocated to these operations, there is a need to complete and/or service wells in an optimal manner and to reduce non-productive time. The present invention was developed to provide an alterative to prior art well completion and work-over operations for wells using horizontal christmas trees.

In the summary of the invention and description which follows, except where the context requires otherwise due to express language or necessary implication, the word "comprise" or variations such as "comprises" or "comprising" is used in an inclusive sense, i.e. to specify the presence of the stated features but not to

preclude the presence or addition of further features in various embodiments of the invention.

Summary of the Invention

The present invention is based on a break-through realisation that deep-set barriers can be relied on to satisfy the statutory requirements for independently verified barriers to be in place at all times between drilling and suspension and/or completion of a well.

The term "deep-set barrier" as used throughout this specification refers to a barrier that is located at or below the lowermost depth of a tubing string hung from a tubing hanger when the tubing hanger is landed in its final position in the body of a horizontal christmas tree installed at a sub-sea well. During installation, the deep-set barriers remain in position until after the horizontal christmas tree, tubing hanger and tubing string have been installed, thus obviating the need to use a BOP stack to supplement well control during this part of the well completion phase.

The term "BOP stack" as used in this specification includes surface BOPs, as well as sub-sea BOPs. The BOP stack would typically comprise a combination of pipe and blind rams, annular preservers, kill and choke lines and may include a lowermost connector and an upper and/or lower marine riser.

According to a first aspect of the present invention, there is provided a method of completing a sub-sea well using a horizontal christmas tree comprising the step of:

maintaining at least two independently verifiable barriers in the sub-sea well during installation of a completed assembly in the well, the completed assembly comprising a tubing string suspended from a tubing hanger installed in the body of the horizontal christmas tree, the

method characterised in that the at least two barriers are at or below a lowermost end of the tubing string when the completed assembly is installed in the sub-sea well.

Preferably, the method further comprises the step of forming the completed assembly by orienting, landing and locking the tubing hanger in a body of the horizontal christmas tree.

Preferably, the method further comprises the step of verifying the integrity of the completed assembly. More preferably, the step of verifying the integrity comprises the step of verifying hydraulic and electrical interfaces between the tubing hanger and the body of the christmas tree. Preferably, the step of verifying the integrity further comprises the step of verifying the pressure integrity of the completed assembly.

Having realised that the running of a sub-sea BOP stack is not necessary when installing the completed assembly, the present invention is based on the further realisation that the steps of landing, orienting and/or verifying the installation of the tubing hanger in the body of a horizontal christmas tree need not be conducted sub-sea. Thus, preferably, the method further comprises the step of forming the completed assembly above the water-line. It is to be understood that a portion of the tubing string hung from the tubing hanger may extend below the water-line during the steps of landing, orienting and/or verifying the installation of the tubing hanger in the body of the horizontal tree, provided that the tubing hanger and horizontal christmas tree *per se* remain above the water-line until the completed assembly is formed.

The advantage of forming the completed assembly above the water-line is that it is much easier to orient, land and

lock the tubing hanger in the horizontal christmas tree and/or verify the necessary electrical and hydraulic connections of the completed assembly in the open air as opposed to performing these operations sub-sea.

An offshore drilling rig typically has a rig floor and a second deck below the rig floor where workers typically access the BOP stack. This second deck is commonly referred to as the "cellar deck", "moonpool", or "Texas deck". In a particularly preferred embodiment, the step of forming the completed assembly may for be conducted on a deck of a drilling rig or vessel and more preferably on a cellar deck of a rig.

It is however to be understood that the completed assembly need not be formed on a deck of a rig positioned above a well. The completed assembly could be formed, by way of example, at a location remote from the rig and transported to the rig as a completed assembly. Similarly, the step of verifying connections could be performed at a location remote from the rig.

Although it is clearly preferable to form the completed assembly above the water-line, there is no reason why the step of forming the completed assembly could not be performed sub-sea. In this less preferable scenario, the horizontal christmas tree would be installed on a well head in the usual fashion. The tubing hanger may be run through a marine riser associated with the horizontal christmas tree and landed in the body of the horizontal christmas tree sub-sea. The integrity of the sub-sea installation of the tubing hanger would need to be verified using prior art techniques. The advantage of not needing to rely on the BOP stack to supplement well control during the step of forming the completed assembly sub-sea still applies in this less preferred scenario.

Preferably, the sub-sea well comprises at least one casing string and the method further comprises the step of installing a liner hanger in the lowermost casing string. More preferably the method further comprises the step of providing a first barrier within the liner hanger and verifying the integrity of the first barrier.

Preferably, the method further comprises the step of providing a second barrier within the liner hanger defining a space between the first and second barriers. More preferably the method comprises the step of verifying the integrity of the second barrier. More preferably still, the method comprises the step of measuring the pressure in the space between the first and second barriers to verify the integrity of the second barrier.

According to a second aspect of the present invention, there is provided a method of completing a sub-sea well using a horizontal christmas tree comprising the steps of:

(a) installing a well head in a sub-sea well;

(b) verifying the integrity of at least two independently verifiable barriers below the well head; and,

(c) installing a completed assembly in the well head, the completed assembly comprising a tubing string suspended from a tubing hanger installed in the body of the horizontal christmas tree, the method characterised in that a lowermost end of the tubing string is at or above the at least two barriers when the completed assembly is installed in the well head.

The need to run the BOP stack has been eliminated by being able to leave both of the at least two barriers in place during step (c).

Preferably, the method further comprises the step of

forming the completed assembly above the water-line. More preferably, the step of forming the completed assembly above the water-line comprises the step of step of landing and orienting the tubing hanger in the body of the christmas tree.

Preferably, the step of forming the completed assembly further comprises the step of verifying the integrity of the completed assembly.

According to a third aspect of the present invention, there is provided a method of completing a sub-sea well using a horizontal christmas tree, the method comprising the steps of:

forming a completed assembly comprising a tubing string suspended from a tubing hanger installed in the body of the horizontal christmas tree; and,

running the completed assembly to a sub-sea well head, the method characterised in that the tubing hanger and the horizontal christmas tree are above the water-line during the step of forming the completed assembly.

Preferably, the step of forming the completed assembly further comprises the steps of orienting, landing and locking the tubing hanger in the body of the christmas tree.

Preferably, the method further comprises the step of verifying the integrity of the completed assembly above the water line. More preferably, the step of verifying the integrity comprises the step of verifying hydraulic and electrical interfaces between the tubing hanger and the body of the christmas tree. Preferably, the step of verifying the integrity further comprises the step of verifying the pressure integrity of the completed assembly.

The present invention allows for the use a 'lower riser package' (LRP) instead of a BOP stack to supplement well control during the step of running the completed assembly to the well head. Thus, preferably, the step of running the completed assembly to the well head comprises the step of supplementing well control using a lower-riser package.

According to a fourth aspect of the present invention, there is provided a method of working over a completed sub-sea well, the sub-sea well having a competed assembly comprising a tubing string suspended from a tubing hanger installed in a body of a horizontal christmas tree, the method characterised by the steps of:

(a) verifying at least two independently verifiable barriers at or below a lowermost end of the tubing string; and,

(b) maintaining the at least two barriers whilst removing the tubing hanger and tubing string from the well head.

Whilst it is possible to conduct work-over operations without removing the christmas tree from the well head, it is preferable for step (b) to comprise the step of removing the completed assembly from the well. Preferably, the method of working over a sub-sea well further comprises the step of conducing remedial work above the water-line. More preferably, the method of working-over a sub-sea well further comprises the step of re-forming the completed assembly above the water-line and returning the completed assembly to the sub-sea well in accordance with the method(s) of well completion outlined above.

According to a fifth aspect of the present invention, there is provided a sub-sea well using a horizontal christmas tree, the well comprising:

a well head;

a completed assembly installed in the well head, the completed assembly comprising a tubing string suspended from a tubing hanger installed in the body of the horizontal christmas tree; and,

at least two independently verifiable characterised in that a lowermost end of the tubing string is at or above at least two barriers.

According to a sixth aspect of the present invention, there is provided a liner hanger assembly for use during well completion and/or work-over operations, the liner hanger assembly comprising:

a first and second independently verifiable barrier positioned within the liner hanger assembly and defining a space between the first and second barriers;

a pressure verification means for generating a signal indicative of the pressure in the space between the first and second barriers;

a pressure signal receiving means for receiving the signal generated by the pressure verification means; and,

a means for transmitting the signal from the pressure verification means to the pressure signal receiving means.

Preferably, the pressure verification means is a transducer.

Description of the Figures

The preferred embodiments of the present invention will now the described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 illustrates a first step in a well completion sequence in accordance with the present invention showing the placement of dual deep-set barriers;

Figure 2 illustrates a next step in a well completion sequence in accordance with the present invention showing the forming of the completed assembly;

Figure 3 illustrates a next step in a well completion sequence in accordance with the present invention showing use of a LRP for running the completed assembly to the wellhead;

Figure 4 illustrates a next step in a well completion sequence in accordance with the present invention showing the completed assembly in position at the wellhead;

Figure 5 illustrates a still further step in a well completion sequence in accordance with the present invention showing installation of dual barriers in the tubing hanger and/or tree cap or combined hanger/cap assembly;

Figure 6 illustrates a final step in a well completion sequence in accordance with the present invention showing a completed well with dual barriers in the tubing hanger and tubing hanger cap; and,

Figure 7 illustrates a preferred embodiment of a liner hanger assembly for use in accordance with the fifth aspect of the present invention.

Description of the Preferred Embodiments

Before the preferred embodiments of the present methods are described, it is understood that this invention is not limited to the particular sequence or types of barriers described. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to limit the scope of the present invention. Unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of ordinary skill in the art to which this invention belongs. Although other types of barriers and particular well completion or work over sequences similar or equivalent to those described herein can be used to practice or test the present invention, the preferred barriers and methods are now described.

A first preferred embodiment of the method of well completion of the present invention is illustrated in the sequence of Figures 1 to 6. It is to be noted that Figures 1 to 6 are not to scale and that the length of various strings of tubing, casing and/or liners will vary depending on the requirements a particular site such as the depth of water above the mudline and the depth of the formation.

With reference to Figure 1, a sub-sea well head 10 is positioned within guide base 12 and a first casing string 14 having a nominal bore of 30 inches. A second casing string 16 having the same nominal bore as the well head 10 is hung in the well head 10 and cemented into position. A third casing string 18 having a nominal bore of 13 3/8 inches is provided within the second casing 16 string. A fourth and final casing string 20 is provided within the third casing 18.

It is to be understood that while four concentric casings are illustrated in Figure 1, the present invention is equally applicable to sub-sea wells provided with any number of casing strings used as required to provide well control for a given formation.

In Figure 1, a sub-sea BOP stack 40 provided with an associated marine riser 42 is positioned at the well head 10 to supplement well control until primary well control can be achieved the by placement of the required at least two independently verifiable barriers.

In the illustrated sequence of Figures 1 to 6, a liner 22 is installed within the final casing string 22 and hung from a first liner hanger 24. A first barrier 26 is installed in the first liner hanger 24. The integrity of the first barrier 26 is tested to ensure that the first

barrier 26 is capable of withstanding formation pressure.

A second liner hanger 28 is positioned within the final casing string 20 above the first liner hanger 24, defining a space 35 therebetween. A second barrier 30 is set within the second liner hanger 28 and the integrity of the second barrier 30 is independently verified.

It is to be understood that the at least two independently verifiable barriers need not be positioned in one or both of the liner hangers providing that both of these barriers are deep-set.

It is to be further understood that the first and second barriers 26 and 30 may be provided in a plurality of forms including, but not limited to, an unperforated liner or casing, a liner top valve, a bridge plug, a pressure cycle plug, a wireline retrievable plug, an expandable plug, a disappearing plug, a rupture disc and/or an inflatable plug. Moreover, the hydrostatic column of fluid in the wellbore may be considered sufficient to serve as one of the barriers provided that it can be independently verified.

With reference to Figure 2, a horizontal christmas tree 50 is positioned on the cellar deck 44 beneath the rig floor 46. A tubing hanger 60 has been installed within the horizontal christmas tree 50. A tubing string 62 is hung from the tubing hanger 50 and is provided with a tubing string barrier 64 in the form of a sub-surface safety valve. The horizontal christmas tree 50 has a body 52 including a shoulder 54 against a correspondingly shaped shoulder 62 of the tubing hanger 60 rests when the tubing hanger 60 has been landed in the body 52 of the horizontal christmas tree 50. The horizontal christmas tree 50 may also be provided with a helix (not shown) to help the final

orientation of the tubing hanger 60 within the horizontal christmas tree 50.

The installation of the tubing hanger 60 is conducted above the water line 66 and, more specifically, on the cellar deck 44 below the rig floor 46 to form a completed assembly 70 that can be lowered into position in the well after the installation has been verified. To verify the integrity of the completed assembly 70, all electrical and hydraulic connections are checked. The completed assembly 70 may also be subjected to pressure testing.

The ability to perform the installation of the tubing hanger in the body of the horizontal christmas tree above the water-line and preferably on the cellar deck of a rig or vessel provides significant advantage over having to perform the installation and verify the connections sub-sea.

With reference to Figure 3, a lower riser package (LRP) 80 is positioned above the completed assembly 70 whilst the completed assembly 70 is on the cellar deck 44. The LRP 80 is provided with rams and/or valves in its vertical bore as a means of supplementing well control. The LRP 80 is further provided with an emergency disconnect/connector and stress joint 90 to enable the LRP 80 to be released if necessary, for example, under rough conditions.

With reference to Figure 4, once the LRP 80 has been installed, the completed assembly 70 and LRP 80 are run to the well head in a single operation using the LRP 80 to supplement well control. During the running of the completed assembly 70 to the well head 10, primary well control is provided by the first and second barriers 26 and 30, respectively, which remain in position.

A tie-back riser, in this example, a monobore completion riser 92 is positioned above the LRP, terminating in a surface tree and/or flowhead 88. The completion riser is supported and tensioned in the usual manner to accommodate movement of the rig due to wave motion. The surface tree assembly 88 in conjunction with the LRP 80 enables adequate pressure control to be maintained to facilitate well clean-up if desired as well as to facilitate any logging and/or perforating operations.

With reference to Figure 4, once the completed assembly 70 has been installed and tested on the well head 10, the installation is verified. Reliance is then placed on the downhole safety valve 64, the rams of the LRP 80 and/or the valves of the surface tree assembly 88 to satisfy the statutory requirement for two independent barriers during the removal, typically by wireline, of the first and second barriers, 26 and 30 respectively. The first and second barriers 26 and 30, respectively are removed at this stage to prepare the well for production.

After the removal of the first and second barriers, 26 and 30, respectively, two new independent barriers must be installed above the level of the fluid outlet port 68 of the completed assembly 70. A tubing hanger plug 96 and an upper tubing hanger or tree cap plug 98 are run down the monobore completion riser 92 and installed in the tubing hanger and/or tree cap respectively to provide these new barriers. Once the integrity of the tubing hanger plug 96 and tree cap plug 98 have been verified, the LRP 80 and its associated monobore completion riser 92 are removed from the completed assembly 70.

With reference to Figure 6, the final step in the sequence of well completion operations is the placement of a debris cap 72, typically using a ROV. The well is then ready for

production.

With reference to Figure 7, a preferred method of providing two independently verifiable deep-set barriers in the form of a liner hanger assembly 110 is illustrated. A first liner hanger 24 is installed in the final (lowermost) casing string 22. A first barrier 26 is provided by means of a first plug 25 positioned in the bore of the first liner hanger 24 and a first annular seal 27 positioned between the first liner hanger 24 and the internal diameter of the final casing string 22.

The first plug 25 may be provided in a plurality of forms including, but not limited to, an unperforated liner or casing, a liner top valve, a bridge plug, a pressure cycle plug, a wireline retrievable plug, an expandable plug, a disappearing plug, a rupture disc and/or an inflatable plug.

The integrity of the first barrier 26 is then verified using known techniques.

A second liner hanger 28 is then installed above the first liner hanger 24 defining a space 35 therebetween. A second barrier 30 is provided by means of a second plug 27, typically a wireline retrievable plug, positioned in the bore of the second liner hanger 28 and a second annular seal 29 positioned between the second liner hanger 28 and the internal diameter of the final casing string 22.

The integrity of the second barrier 30 may then be verified. It has been previously considered that barriers relied upon to provide primary well control during well completion and/or work-over operations should not be positioned in close proximity to each other. This is because it is considered to be difficult to verify the

independence of the second barrier if the space between the two barriers has a relatively small volume.

This problem is overcome in the illustrated embodiment of Figure 7 by providing the second barrier 30 with a pressure verification means in the form of a pressure transducer 112. The pressure transducer 112 generates a signal indicative of the pressure in the space 35 defined between the first and second barriers, 26 and 30 respectively. The signal from the pressure transducer 112 is transmitted using any suitable means such as a wireless signal, breakable hard wire link or disconnectable hard wire line to a pressure signal receiving means 114.

In the illustrated embodiment of Figure 7, the pressure signal receiving means 114 is incorporated in a plug running tool 116 in electrical communication with a means for interpreting the pressure signal (not shown) positioned above the water-line, typically on the cellar deck 44 of the rig floor 46.

In a third preferred embodiment of the present invention, the first and second barriers 26 and 30, respectively, are pre-installed within the liner hanger assembly 110. In this embodiment, the integrity of the pre-installed first and second barriers 26 and 30, respectively can be verified before or after the liner hanger assembly 110 is placed in the liner 22.

In use, the liner hanger assembly 110 complete with pre-installed and pre-verified first and second barriers 26 and 30 is positioned towards the lowermost end 118 of the final casing string 20. The signal from the pressure transducer 112 is received and interpreted by the pressure signal receiving means to re-verify the integrity of the first and second barriers 26 and 30 after the liner hanger assembly

has been installed sub-sea.

When it is required to perform a work-over operation on a sub-sea well, a similar sequence of steps are performed in a different order. For example, a work-over may be performed to recover failed christmas tree or a failed tubing hanger. The at least two independent barriers are reinstated and verified to provide primary well control prior to the removal of the tubing hanger 50 and/or completed assembly 70. The use of deep-set barriers enables the work-over operation to be conducted without the need to run a BOP stack to the well.

A typical sequence for a work-over operation is developed below with reference to Figures 1 to 6. As described above in relation to well completion, it is to be understood that the particular sequence of steps will vary depending on the objective of a particular work-over operation.

As a first step in a work-over operation requiring removal of the completed assembly 70, the debris cap 72 is removed, typically using an ROV. The LRP 80 and EDC 90 are prepared on the cellar deck 44 and run to the well. When the LRP 80 is in position above the christmas tree 50, the surface tree 88 is made up in the usual manner and the LRP 80 is run to the well and installed on top of the horizontal christmas tree 50.

The integrity of the connections between the LRP 80 and the horizontal christmas tree 50 is verified, typically by way of pressure and other function tests. Once the LRP 80 is in position, the rams of the LRP 80 in the vertical bore are can satisfy the statutory requirement of two independently verifiable barriers, enabling removal of the tree cap and tubing hanger plugs, 98 and 96, respectively. Typically, these plugs are recovered by wireline.

The next step is to reinstate the first barrier 26, in this example, in the first liner hanger 24. The integrity of the first barrier 26 is vented, typically, by way of pressure testing. Once the integrity of the first barrier 26 has been verified, the second barrier 30 is installed in the second liner hanger 28 and verified in the usual manner.

Once the integrity of the first and second barriers, 26 and 30, respectively, has been verified, the completed assembly 70 is unlocked from the well head 10 and retrieved above the water-line. The first and second barriers 26 and 30, respectively, are relied on to satisfy the statutory requirement for two independently verified barriers to provide primary well control during a work-over operation.

The completed assembly 70 is pulled apart are required to perform the necessary remedial, maintenance or other repair work required for the tubing hanger and/or horizontal christmas tree. This work is conducted, typically on the rig floor 46 or the cellar deck 44. Once the repair has been effected, the completed assembly 70 is reformed above the water-line and returned to the well using the procedure as described above in relation to performing a well completion.

It is to be understood that a work-over operation may also be performed in accordance with the present invention without removal of the christmas tree if desired. In this scenario, the LRP 80 and its associated tie-back riser 92 is run to the well as described above, enabling removal of the tree cap and tubing hanger plugs, 98 and 96, respectively. The first and second deep-set barriers 26 and 30 are installed and verified as previously described.

In order to remove only the tubing hanger 60 along with the tubing string 62 suspended from the tubing hanger 60, it is the LRP 80 is unlocked from the christmas tree 50 and retrieved to the rig floor 46 or cellar deck 44. A tubing hanger running tool (not illustrated) is run to the well to unlock and retrieve the tubing hanger 60 and tubing string 62 leaving the christmas tree installed at the well head 10.

Now that the preferred embodiments of the present invention have been described in detail, the present invention has a number of advantages over the prior art, including:

(a) elimination of the need to run a BOP stack for the second time during well completion operations with horizontal christmas trees;

(b) the ability to perform installation of the tubing hanger in the horizontal christmas tree above the water line is a far easier operation than performing this operation sub-sea and simplifies any remedial actions;

(c) elimination of the need to use a sub-surface test tree to provide well control when using horizontal christmas trees;

(d) the ability to use a lower riser package (LRP) in place of SSTT. The LRP is considerably more robust and reliable and eliminates the need to source and interface with high-cost rental equipment;

(e) the ability to use a lower riser package for work-over operations and interventions also presents significant cost savings by eliminating the traditional requirement to use a drilling BOP stack and marine riser in conjunction with a sub-sea test tree and tie-back riser;

(f) the risk of debris entering the horizontal tree during the tubing hanger/tree cap installation operation is removed; and,

(g) the ability to make up and verify all electrical and hydraulic connections and penetrations above the water-

line.

Numerous variations and modifications will suggest themselves to persons skilled in the relevant art, in addition to those already described, without departing from the basic inventive concepts. All such variations and modifications are to be considered within the scope of the present invention, the nature of which is to be determined from the foregoing description.

Dated this 8th day of August 2003

WOODSIDE ENERGY LTD
By Its Patent Attorneys
GRIFFITH HACK

Fellows Institute of Patent and Trade Mark Attorneys of Australia.

Figure 1

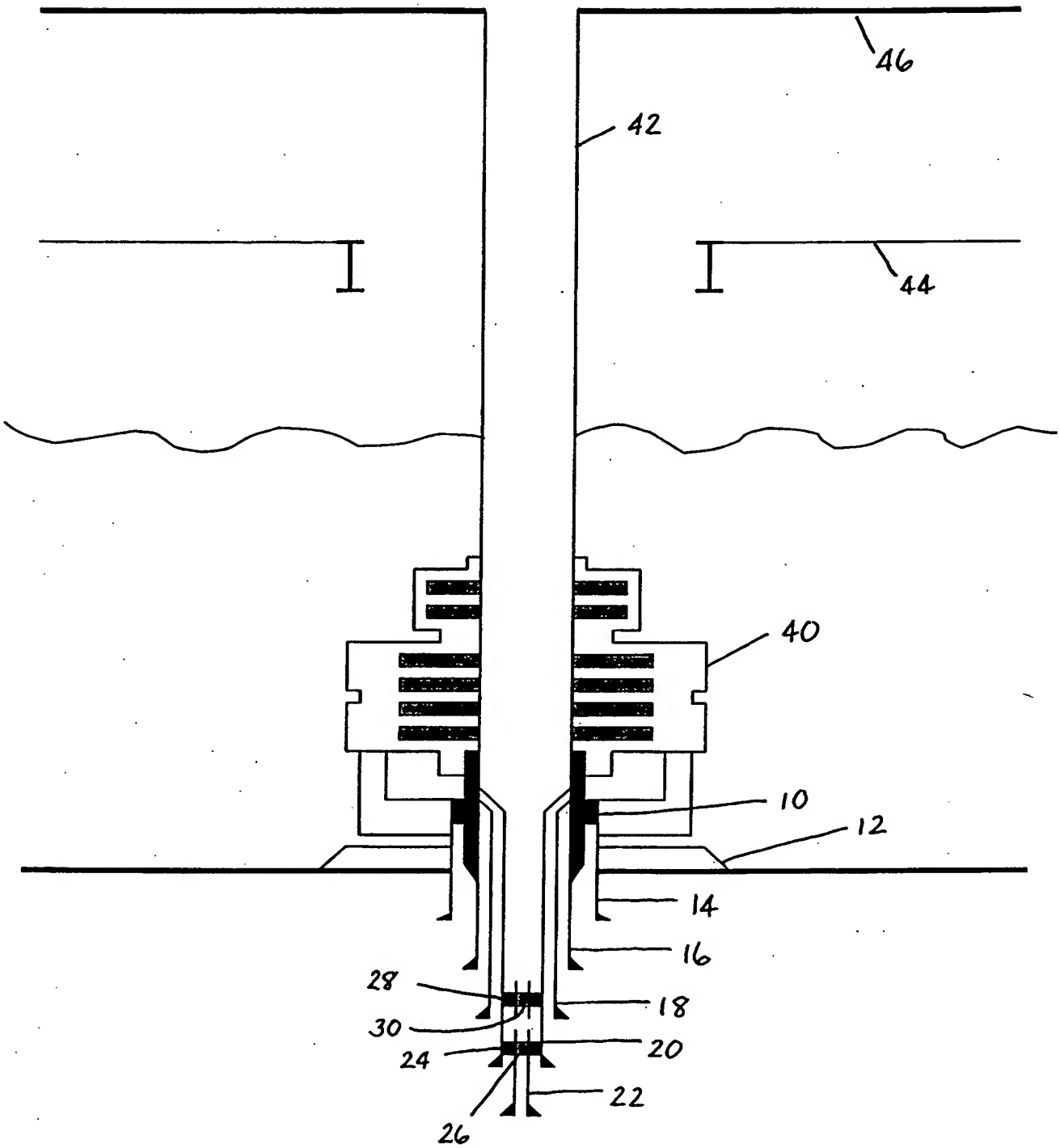

Figure 2

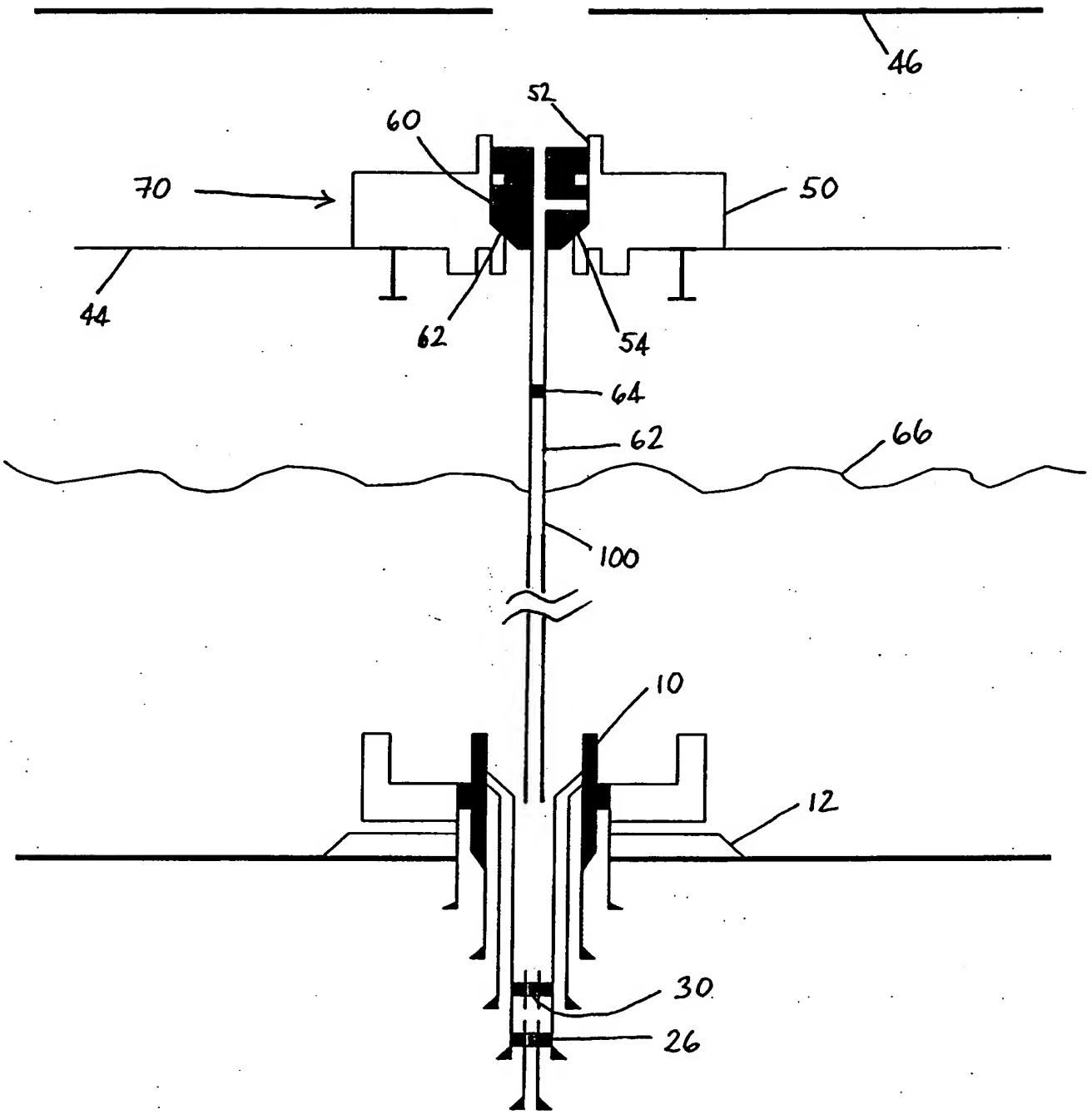

Figure 3

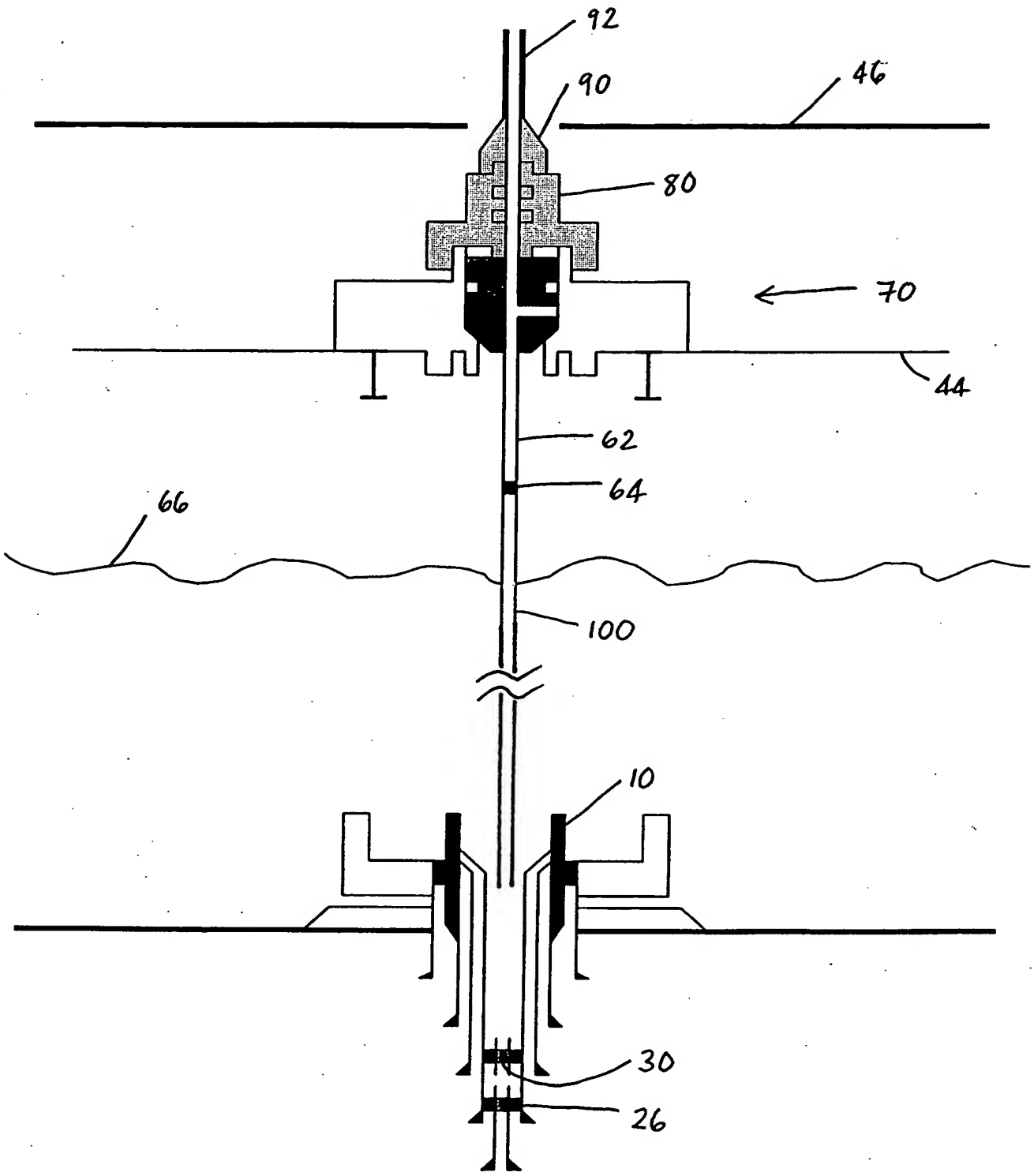

Figure 4

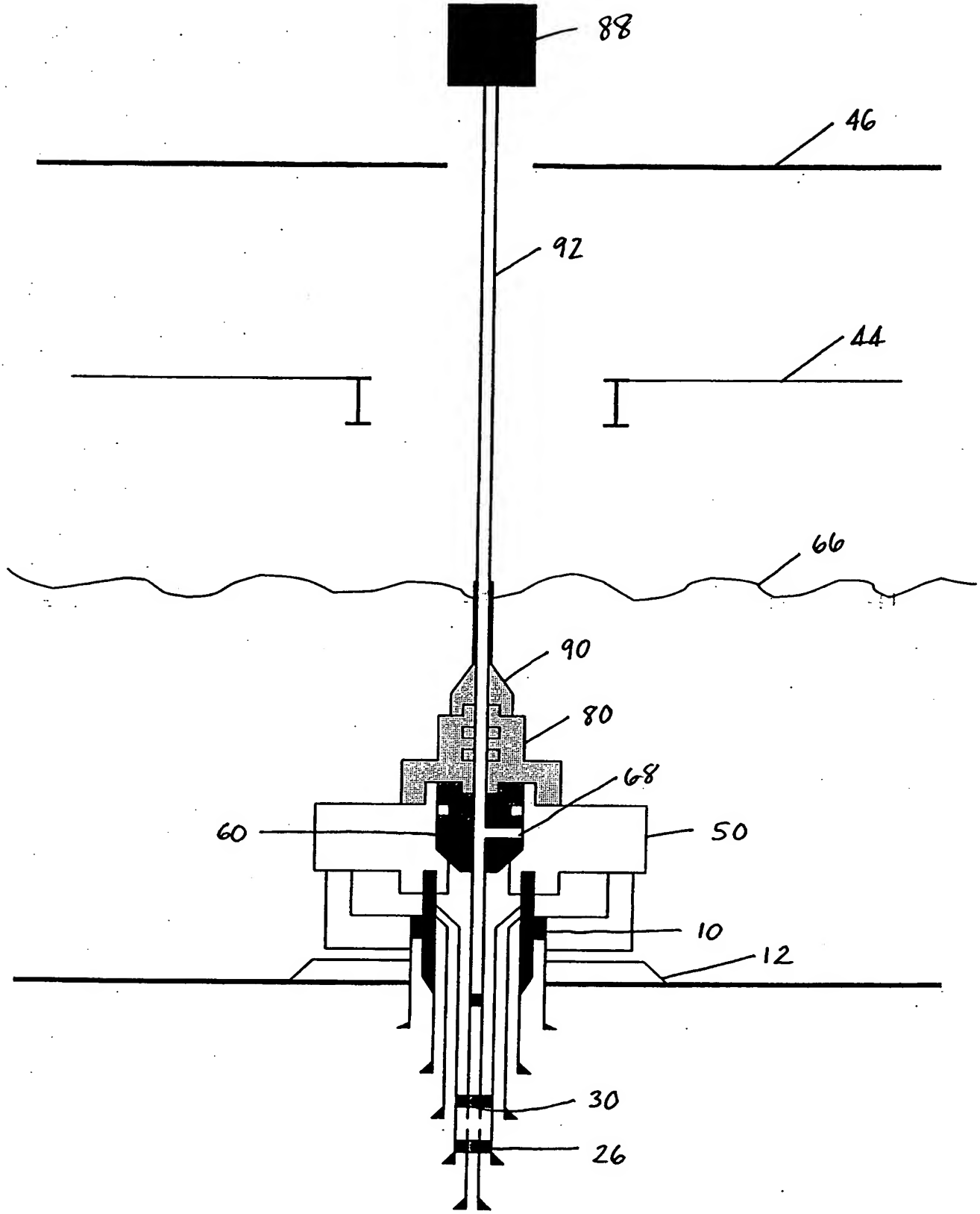

Figure 5

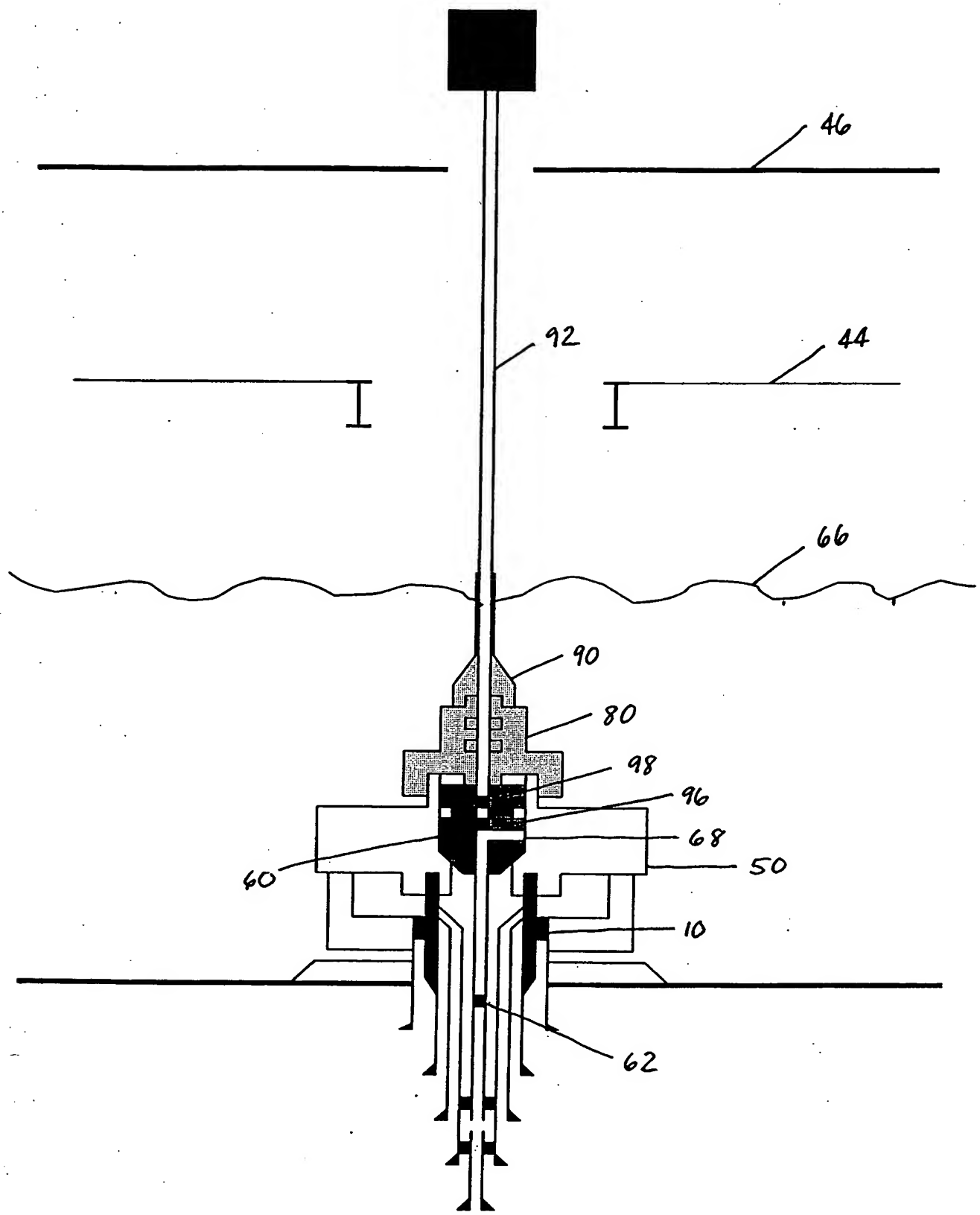

Figure 6

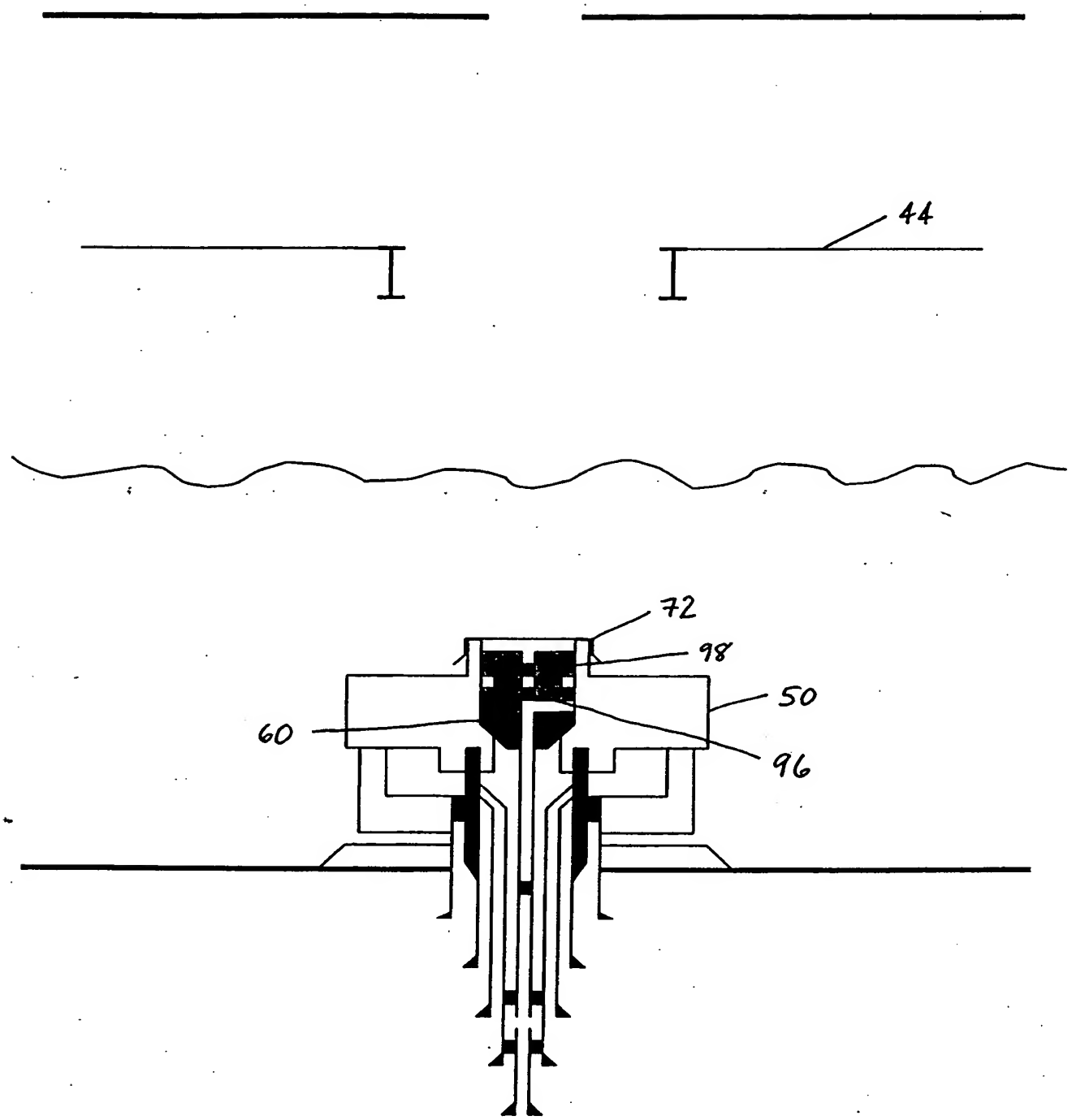

Figure 7